The Co-evolution of Technologies and Markets - On Market Transparency in Nanotech Evolution

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The Co-evolution of Technologies and Markets

- On Market Transparency in Nanotech Evolution

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Abstract

This paper suggests to look into the market formation processes related to emerging technologies, using nanotechnology as a case. This is in contrast to the usual focus on knowledge generation aspects when analyzing technology evolution in evolutionary economic research. Although nanotechnology is an emerging technology at an infant stage of commercial development expectations to its economic and societal impacts are huge. However, despite ongoing large investments globally, the rate of commercial development is slower than expected. The reasons seem to be rising concerns about risks to health and the environment associated with nanotechnology. There are some early indications that firms are developing new nano strategies where nano activities increasingly are treated discretely. The paper investigates these trends using the flat glass industry as case based on bibliometric studies and other company communication as well as in depth case analyses. The paper concludes tentatively that while the market for nano products seems to approach commercialization it is becoming still less transparent. This may have important implications for the further commercialization of nanotechnology, which are discussed in

the paper. The analysis feeds into evolutionary economic research on technology and economic evolution and corporate strategizing and business models related to emerging technologies.

Keywords: Emerging technologies, technological evolution, nanotechnology, market formation, market transparency, standardization, strategy, business models, branding, risks, evolutionary economics

1. Introduction

Nanotechnology is at a very infant stage of development and it therefore allows us to study the very early phases of an emerging technology in real time. Nanotechnology is characterized as a "general purpose technology" by innovation researchers – a generic technology with enabling properties and pervasive major impacts throughout the economy (Bozeman et al. 2007; Youtie et al. 2008; Mangematin and Rieu, 2009). The technology has from the start been surrounded by hype and associated with grand promises to become an important driver of global economic and social development possible representing the next technological revolution (Royal Society, 2004; Nanoforum 2004; Aitken et al., 2006; NSET, 2009). It is a priority area in most countries and continuous to attract huge investments globally despite the fact that the commercialization of nanotechnology is slower than originally expected (Delamarle et al. 2009; Laredo, Delamarle and Kahane, 2010). (Lux, 2007; NSET, 2009). Most innovation economic research into emerging technologies are inspired by research into industry life cycles and focuses on analyzing the time scales and innovation conditions in different phases of nanotechnology development with a main focus on the input side (knowledge and technology generation) of the innovation process. (e.g. Meyer, 2002; Rothermal and Thursby, 2007; Mangematin, 2008; Mangematin and Rieu, 2009; Delamarle et al. 2009; Mowery 2010, Islam and Miyazaki, 2010). This paper argues that important aspects of technology and economic evolution may be understood by focusing on the output side, the

commercialization and market formation aspects connected to emerging technologies which hitherto have been little investigated (Shapira, Youtie and Kay, 2010).

This paper applies a dynamic (or evolutionary) capabilities perspective in looking into corporate strategizing and business models towards an emerging frontier technology. An overlooked aspect in the economic literature is how firms choose to communicate their inventive activities in the early fluid stages of an emerging technology when uncertainties and risks are high. Hence this paper looks into the emergence of nanotechnology as a criterion in market selection. The analysis feeds into more undamental understandings in evolutionary economics into the co-evolution of technologies and markets. The paper investigates the proposition that the hype is a distinct feature of nanotechnology that affects market formation.

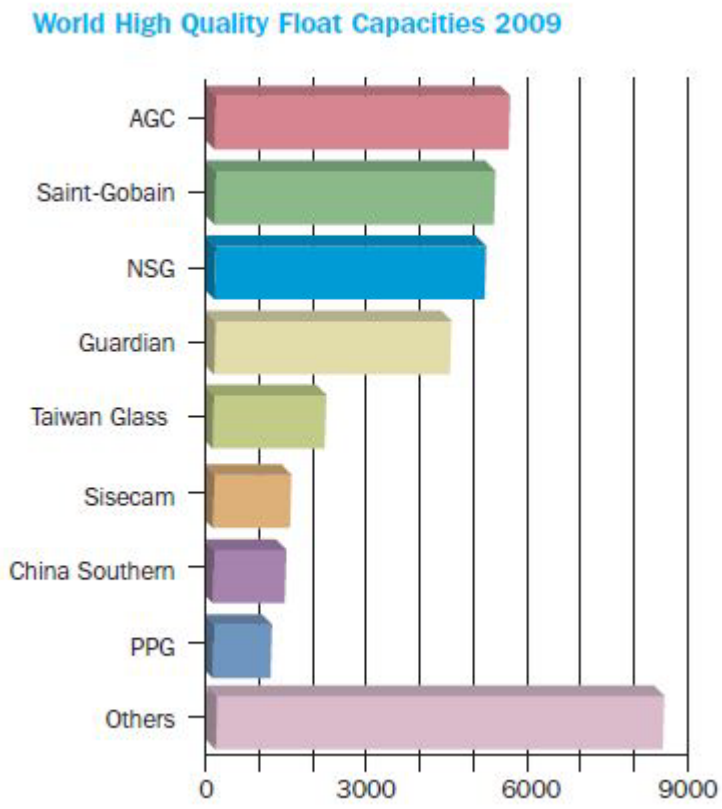
The flat glass industry is a sector where nanotechnologies are already well integrated and has therefore been chosen as a case. Over the past 30 years, product innovation in flat glass has developed tremendously turning glass from simple glass products into high-quality products . They are used, on the one hand, to coat thinner films on float, permitting the accumulation of lots of different coating without widening the float and on the other hand, to give the material special properties. These include thermal insulation, solar control (to reduce heat loss and regulate ventilation), security and safety, fire resistance, noise reduction, anti-reflection, self-cleaning, anti-scratching, and visual appearance. Nano-based coatings has played an essential role in this development, evolved through incremental trial and error long before the recent buzz associated with nanotechnology but accelerating with the advance of modern nanoscience in the 1990s. Today's glass coatings are multi-layer, up to 7 or more layers, to achieve multifunctional glass.

The multinational glass companies have taken the lead in developing advanced nano-coatings. According to Pilkington Denmark, the competition in glass is intense and highly technology-based. Modern glass production is continuous, large-scale mass production, and very capital intensive. Concentration in the sector is accordingly high, with the four largest global players – NSG (since 2006 including the large UK Pilkington Group), Saint Gobain Glass, Asahi and Guardian Industries – holding

alone a combined share of around 80% of the flat glass market in Europe in 2004.[1] All the big glass players have extensive R&D activities and a varied product portfolio in flat glass production directed at their two major markets, the construction sector (80 percentage) and the more innovative automotive/transport sector (10 percentage). Most of the parent glass companies have extensive activities in other (non-glass) parts of the construction sector, including materials and chemicals, sectors of central importance for nanotechnology development.[2]

The main companies are the following :

Figure 1 The main flat glass companies and their capacities



Source: NSG Group - Pilkington and the flat glass industry, 2010

[1] Source: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1781, 2007.
[2] See also Pilkington (2009a).

The motivation of this paper is based on the findings from a recent qualitative study on the uptake of nanotechnology in the window chain, including the central European flat glass company Pilkington as well as other firms in the Danish window chain (Andersen et al. 2010; Andersen, 2011). There is generally a low-level deployment of nanotechnology in the traditional construction sector (Gann, 2003; Crisp/SPRU 2003; Bartos et al., 2004; Zhu et al. 2004; Fellenberg and Hoffschulz, 2006; Andersen and Molin, 2007; Geiker and Andersen, 2009). However, there is quite a high number of nanotechnology applications in the Danish window chain. There are important fully commercial nano-enabled products plus a variety of development projects and emerging new nanotechnology applications. Start-ups, the major multinational companies, and – perhaps most surprisingly – small to medium sized incumbents all play important roles in the development and uptake of nanotechnology in the window chain. This study had a focus not only on the nano R&D but also on the market formation aspects in studying nanotechnology evolution. It showed a tendency for quite many firms to be discrete or 'silent' about their nanoactivities. The nano content of products in the Danish window chain is little known in the wider public domain but also among many professional users; none the least among the many none-science based firms in the construction sector. Hence, the market transparency is low and 'nano' functions only little as a selection criteria on the market (Andersen, 2011). The way this may influence on the further commercialization of nanotechnology is in need of further study, depending none the least of the scope and direction of this possible trend.

While the public perception of nanotechnology has been widely studied, there seems to be very little research into firm perception, business models and communication strategies except for a small French study (Novethic 2010)[3] . This study investigated the public nano communication of large (MNC) listed nanoactive companies covering 92 companies in 12 sectors. Hence only relatively few companies per sector were covered. The analysis concluded that a little over half of the companies (54 pct.) were entirely

[3] The Novethic study was ordered by an insurance company. Novethic is a research center focusing on Corporate Social Responsibility and investment research.

silent about their nano activities. Only 3 companies had detailed communication about their nanotechnology activities and these were all from the chemical industry, i.e. at the very upstream part of the nanotechnology chain involved in the production of nano materials, where communication needs on nano products and properties are great. Also this is a sector who is accustomed to risk management and risk communication. The rest had 'basic' communication on nanotechnology which to a large degree covered 'eye catching slogans on the positive impact of nanotechnology' (Novethic 2010). Of the six construction companies, four were silent and two had basic communication. We will return to both these studies later.

This paper is a first attempt at expanding the qualitative analysis mentioned into an in depth quantitative study in a specific sector, exploring into the wider scope and direction of the nano market formation trends. The analysis is based on a bibliometric study in the flat glass industry. The flat glass industry has been chosen because they are the key nano producers in the window chain, hence expanding directly on the former mentioned case study (Andersen, 2011). The high R&D intensity of this sector allows for bibliometric studies as a proxy for R&D activity. Also, since very few very large players dominate the sector, a study into a few players' activities should give an illustrative, if not entirely representative picture of what is going on. This paper explores the hypothesis that the size and age of the firm influences on its nano transparency. The expectation is that the big firms are more attentive to protecting their brands and have developed strategies and business models for handling their nanoactivities, which the new and smaller firms may not have. Brand protection may though both lead to a nano 'loud' communication strategy and a nano silent communication strategy. A comprehensive study of the scope of this trend hence needs to look into the nanostrategies of a wide sample of different types of firms, which though, goes beyond this paper. Hence the conclusions should be treated as partial, only covering the strategies of the very large players.

The method applied has been to track the scientific nano publications of selected main flat glass companies through the years as indicator of the firms nano activities but also to track the explicit versus tacit scientific nano communication and not only the public nano communication. These are then compared to the firms' public communication on nanotechnology (on the web, in company reports and other written company material) (as indicators of the firms' nano marketing or transparency) using the methodology of Novethic (2010). Due to methodological challenges (see further below on methodology), the analysis is delimited to four main large companies: Pilkington (the main European part (UK based) of the Japanese based NSG Group), the French based Saint-Gobain Group, and the American based PPG group. On the (easier) public communication further three large flat glass producers are included.

The structure of the paper is as follows:
In section two some qualitative findings on the co-evolution of nanotechnology and the market for nano products is given, focusing on the nano strategies of the flat glass producer Pilkington and some other main players in the Danish window chain. In section three the methodology of the bibliometric study is explained. Section four focuses on analyzing nano innovation and nano transparency over time in the three main companies. Section 5 contrasts this with an analysis of the public communication of the main companies. Section 6 concludes.

2. The nano communication strategies of Pilkington and VKR in the Danish window chain

In this section the main findings from a qualitative study into the uptake of nanotechnology in the Danish window chain is shortly given focusing on the market communication and transparency aspects. The analysis is based on interviews conducted in 2009-2011, and also web-based information, secondary data, a national survey, and earlier studies by the author on innovation in nanotechnology, green nanotechnology and nano-enabled construction (see Andersen and Rasmussen, 2006; Andersen and Molin, 2007; Geiker and Andersen, 2009; Andersen and Geiker, 2009, Andersen, 2010; Andersen et al.,

2010; Andersen, 2011). [4] This analysis, while only covering two relevant companies for flat glass production, Pilkington Denmark and the next step in the value chain, the large Danish window producer VKR Holding Group, may provide some explanation for the drivers and trends described in the quantitative analysis succeeding.

The Vertical specialization in the window chain is characterized by a few very large advanced multinational glass manufacturers, many small mostly traditional glass processing and window producers, and a range of project-oriented construction companies. In Denmark there is no float glass production left. Since the 1970s, the national offices or subsidiaries of the multinational companies Pilkington and Saint Gobain have dominated the Danish and Nordic glass supply and distribution markets. The window industry, on the other hand, the next step up the value chain, is still dominated by many small local players; in Denmark around 300 small producers, but the industry is dominated by one large group, the multinational VKR Holding Group. VKR has quite a high level of R&D, on the glass pane as well as the frame, and is the locus of most of the nanotechnology activities in the Danish window industry.

Pilkington is famous in a nano commercialization context because they launched the first self-cleaning glass in 2001.[5] Self-cleaning glass became recognized internationally as one of the first commercially-available nano-consumer products. Within a year, PPG Industries, Cardinal Glass Industries and Saint Gobain also launched their self-cleaning glass products. Self-cleaning glass is now widely available in glass wholesalers' product portfolios, although it still awaits a major breakthrough in market demand. It is still among the well-known nano products and the only glass product with a nano reputation, despite the widespread use of nanotechnology in modern glass production. However, despite the publicity ("nano-fame") associated with its self-cleaning glass, Pilkington does not officially refer to it

[4] The analysis draws on findings from the Nordic study *Green Nanotechnology in Nordic Construction – Eco-innovation Strategies and Dynamics in Nordic Window Chains.* See Andersen et al. (2010 and Andersen, 2011) for a further account of the methodology used and more detailed empirical analyses.

[5] Self-cleaning glass cleans itself through photocatalytic processes. *The Pilkington Activ* brand by Pilkington uses a 15 nm thick transparent coating of microcrystalline titanium dioxide. The coating is applied by chemical vapor deposition. Self-cleaning glass lowers maintenance requirements, reduces outside condensation (a rising problem in energy efficient houses), and saves detergents, water and energy use (Pilkington 2009b).

as an application of "nanotechnology".[6] The term "nanotechnology" is generally avoided and instead they use the traditional term of "coatings". The company maintains a low profile related to nanotechnology, and, as we shall return to, there is little reference to nanotechnology in their public communication.

According to Pilkington Denmark, the motivation for their low profile is three-fold: It is partly based on tradition. Pilkington has been developing advanced nano-coatings for over thirty years, long before the nano-buzz took off, and they see little reason to change their routines and start calling their well-proven coating technologies for nanotechnology. The second factor is the unsettled debate on nanotechnology risk issues, related to the possible negative effects on the environment and human health, which remains an ongoing important issue. The third reason is because of the considerable uncertainty as to what is nanotechnology what is not. Examples of "nano-fakes" have created negative reactions from customers. Overall, Pilkington currently sees no market advantage or profit opportunities in "nano-marketing" to emphasizing their product's nanotechnology characteristics. Cornmenting on the self-cleaning glass they declare that the product should be considered a 'thin film' technology rather than a nanotechnology product, even though the coating falls within the official definition of nanotechnology[7], illustrating the eagerness to avoid the nanoterm and certainly any association with nanoparticles.

According to Pilkington Denmark, self-cleaning glass has been a big market flop. Apparently not because of a possible nano-association; rather there are, still according to Pilkington, overall general barriers in marketing advanced glass innovations. The builder, who typically will not live in the house, has little incentive for product innovation to reduce user costs. Since advanced nano-coated glass products have their advantages in the user phase, this is a major barrier for product innovation. The window and wider construction sector is not viewed as innovative and as lacking knowledge about glass. The

[6] According to interviews with a top manager at Pilkington Denmark in 2010 and 2011.
[7] For *Pilkington Activ*, Pilkington states on their web: "Whilst the coating is nanometres thick it is really a development of thin film technology, rather than being a specific nanotechnology product. The name nanotechnology is usually applied to the scientific investigation or application of particles and/or structures which have sizes of less than one hundred nanometres. Particles or structures of this size can have unique properties compared with bulk materials. Pilkington Activ™ is based on a thin film of titanium dioxide rather than particles of titanium dioxide and the film is approximately 15 nanometres thick."
http://www.pilkingtonselfcleaningglass.co.uk/faq/technical/ (accessed February 2, 2011).

construction sector is generally focused on production costs, while ongoing user costs are neglected. The market for flat glass is therefore driven very much by regulation, which has been dominated none the least by the marked rising demand for energy efficiency and -control the last 20 years, while there is a lack of regulation for self-cleaning features. Low emissivity and solar control glass are standard offerings in today's markets, achieved via nano-coatings. Pilkington Denmark sees the Nordic countries as being in the lead for taking up new advanced glass products and has therefore based its largest glass coating plant in Sweden. The branding of Pilkington's products is the same everywhere in the world. This "silent" attitude to nanotechnology is shared by many of the other big glass companies as we shall return to, and many of the other firms in the window chain to varying degrees.

VELUX is the dominant company within the VKR Group, with a well-known international brand in roof windows and skylights; it is the main nano-active window producer in the VKR Group.[8] Nanotechnology has long been of interest to VELUX because it plays an important role among a number of their suppliers, particularly their many large multinational suppliers, and in the components of their products. VELUX has its own R&D department, which is divided into two sections, one for the frame and one for glass. Both sections are involved in nanotechnology R&D. They track developments among their suppliers so that the company has the necessary capabilities to select the right products from their suppliers. Glass features is a key competitive factor and knowledge and insight about nanotechnology is especially important in the glass R&D section but is becoming more important in the frame section lately. They maintain dialogue with the major glass producers about their nano-coatings and are well informed about all details of these.

Over the last ten years VELUX's interest in nanotechnology has grown parallel to the general rising societal interest about nanotechnology, and they have e.g. taken part in nano R&D projects and in the nano background group of Danish Standards. Nano-coated multifunctional glass is stocked in VELUX's product portfolio, and e.g. low-E glass and solar control glass are standard products on all markets today. The self-cleaning glass is important to Velux, because the roof windows are difficult to

[8] This section is based on interviews with managers at VELUX in 2009, 2010 and 2011.

clean. In some countries, it is offered as a standard window material, while in other countries it is an optional choice.

For VELUX nanotechnology is seen as an R&D input rather than a product criteria. They do not undertake explicit nano-marketing and there is no company information about nanotechnology content or production processes in product descriptions. However, risk aspects are an issue they are very attentive to in their nanotechnology strategy development. They see two poles in the nanotechnology community. The first focuses on health and environmental issues, claiming that nanotechnology is risky. The second maintains that there are no problems to stop pushing ahead with these promising technologies. VELUX seeks a middle way between these poles, keeping careful track of developments related to nanotechnology risks generally as well as on their products as part of their wider sustainability and cradle to cradle strategies, while maintaining a low marketing profile on nanotechnology.

The other nano-active companies analyzed in the Danish window chain were mainly dedicated nano-upstarts who displayed a more outspoken nano communication strategy, in several cases marketing themselves positively as high tech nano companies. But even for these the nano marketing is becoming less pronounced and even discrete in the later years as compared to the early 2000s when the nano hype was at its hottests.

3. The methodology of the bibliometric study

Nanoscience and nanotechnology are as yet a young fluid concept and subject to much ongoing formal standardization work. Currently, it is still hard to detect what is and what is not nanotechnology in bibliometric studies, as the term nanotechnology is often not referred to in detailed scientific publications. Hence careful attention to the methodology of the bibliometric study is essential for achieving a high explanatory value from the analysis. Naturally, bibliometric studies are only a proxy for the level of nano-related research and production; In the flat glass production there are currently no articles which gives a

systematic overview of the use of nanotechnology in research or production hence this study starts from scratch in identifying the extent of nano R&D.

The largest flat glass producers were targeted for the analysis. The publications of the companies were extracted from Scopus (ScienceDirect) and includes all the articles published by Pilkington (a main part of the NSG Group), Saint-Gobain, PPG, Sisecam, NSG and AGC. (see table 1). No article published by Guardian could be found on Scopus for an unknown reason; also Taiwan Glass and China Southern publish their articles in Chinese so these firms are not included. The articles were extracted between July and August 2011.

Table 1 Number of imported likely nano articles from the main flat glass companies

Company	Number of articles	Rank (in terms of High Quality Float Capacities)
Pilkington (owned by NSG)	321[9]	3rd (forms a major part of NSG)
Saint-Gobain	730	2nd
PPG	558	8th
Sisecam	22 (not included)	6th
NSG	365	3rd
AGC	1214 (none analysed – only public communication (see later))	1st

Of these companies only four have been analyzed in depth due to the quite demanding methodology. Sisecam was excluded because of the small number AGC is included in the public communication analysis only. The group, which is the largest flat glass producer in the world, seems to have an extensive

[9] In 2006 the large Pilkington Group was bought up by the NSG Group, turning NSG into one of the largest flat glass Groups in the world. There are 5 articles overlapping between the Pilkington and NSG analysis only.

nano R&D, in fact by far the largest of the big players analyzed, which it could be interesting to study further.

An algorithm was made adapted from a study on refining search terms for nanotechnology (see Porter, Youtie, Shapira, Schoeneck, 2007), using Microsoft Access Office and VBA language. The following fields were extracted: Title, Year, Abstract, Author Keywords and Index Keywords. The goal of the algorithm is helping to determine whether a publication concerns nanotechnologies. In Porter et al. 2007, the algorithm has three steps: the first one aggregates the maximum of articles by combining different keywords related to nanotechnologies. The elimination of parasite articles is made first by a combination of particular keywords and then by an expert analysis. This algorithm should be able to be used on any field of nanotechnologies. In order to carry out an in depth analysis in the flat glass industry we suggest to adapt the algorithm and identify specific 'nano' keywords according to the industry. Identifying these technical nano keywords is based on search terms suggested by scientific papers on nanotechnology in flat glass production and coatings. The identification of the nano articles has taken place in three steps: Table 2 details the keywords used for selecting the articles that may deal with nanotechnologies in the flat glass industry in the first step. In this step, it is assumed that if an article is related to nanotechnologies in the flat glass industry, it must contain one of these keywords either in the title, author or index keywords or in the abstract.

Table 2 Nano keywords specific to the flat glass industry

Mater	Biolog*
Film	Monolayer
Coating	STM
Polymer	X-Ray photoelectron
Molecul*	self-cleaning
Nano*	Tunnel* Microscopy

# nm	Fullerene
TEM	Supercritical
Transmission Electron Microscopy	HRTEM
Sol?Gel	Dendrimer
Chemical Vapor Deposition	Quasicrystal
Scanning Electron Microscopy	electron energy loss spectroscopy
Plasma	energy dispersive x-ray
Colloid	EDX
Atom* Force Microscopy	Blodgett
SEM	Mesoporous
EELS	quantum well
Multilayer	quantum dot
AFM	CVD
Quantum	self-assembl*
Array	

stands for a number - ? stands for a single letter - * stands for no, one or several letter(s)
Source: Moderated from Porter et. al. 2007 by selecting the keywords relevant to flat glass production and adding 'self-cleaning' as a keyword.

This step operates a first selection in the amount of the companies' nano publications. The second step in the process consisted in confirming if these articles are effectively nano-related. The keywords selected for this are provided in table 3.

Table 3 - Keywords used for confirming the articles that effectively deal with nanotechnologies

nano*	HRTEM
Colloid	Blodgett
Quantum	quantum well
Supercritical	quantum dot
Fullerene	self-assembl*

Source: Porter et. al. 2007

The third and last step consists in an expert analysis to determine if the remaining articles, not selected by the second step, are related or not to nanotechnologies. Most of the articles were deeply analysed. The analysis often consisted in determining if the coatings studied were less thick than 100nm according to the definition of a nanomaterial which has one or more external dimensions in the size range 1-100nm which gives rise to new product properties (European Commission, http://ec.europa.eu/environment/chemicals/nanotech/). For the intermediate cases, it was studied if the thickness of the coating had a consequence on the material properties by being thin; should the case arise, the article was considered as nano-related. Nonetheless, access to some articles could not be found.[10] . Moreover, the question whether an article deals or not with nanotechnologies could not be settled for a few ambiguous fields such as synthesis processes (plasma technology, sputtering, chemical vapor deposition…), processes using laser technology and chemistry (gels, particles…) mostly; some of these were sought settled in dialogues with experts but this was not always possible. Altogether, there are some minor uncertainties in the identification of nano-related scientific articles, between 3-9 pct.could not be classified, see table 4 which confirms the need for clearer definitions and standards of nanotechnologies and in-depth investigations in specific technology domains.

A further analysis was then made on the explicit nano scientific communication; i.e. whether the nano-related scientific articles identified explicitly include the prefix “nano” in their title, abstract or keywords. Table 4 presents the number of articles remaining after each step for the three main case companies as well as the number of articles including the prefix “nano”:

[10] IN Scopus only the batract is available and not the full article. In some cases the abstract was not enough to Assure whether it was nanotechnology, e.g. in the case of PPG there were 25 out of 558 such articles.

Table 4 - Number of articles at each step of the algorithm

	Pilkington	**Saint-Gobain**	**PPG**	**NSG**[11]
Total number of publications	**321**	**730**	**558**	**365**
Number of selected articles after the first step	158	480	309	249
Number of articles confirmed by step 2	14	82	31	56
Number of nano-related articles after step 3 (includes articles of step 2) *Percentage of nano-articles of total publications*	39 *12%*	200 *27%*	68 *12%*	129 *15%*
Number of articles including the prefix "nano" *Percentage of explicit nano-article out of nano-articles*	10 *26%*	67 *34%*	21 *30%*	29 *22%*
Number of articles that could not be classified	19 *(6%)*	47 *(6%)*	19 *(3%)*	34 *(9%)*

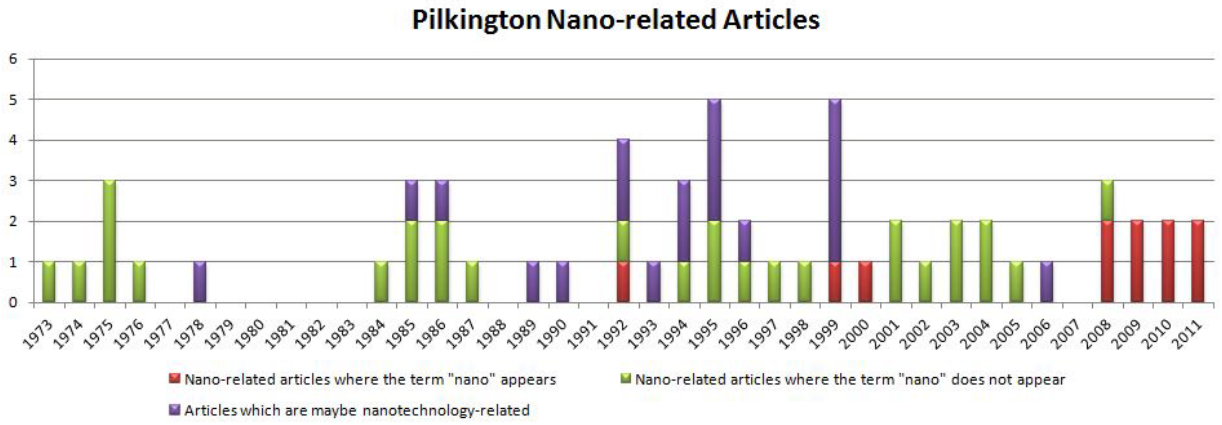
From the overall findings from table 4 it appears that the percentage of nano articles of all the scientific articles of the companies is of some size: Pilkington, PPG and NSG are at much the same level (12-15 pct.) while Saint Gobain is considerably higher, more than a fourth (27pct.). Of these, however, only between 22 and 34 pct are explicitly referring to the term nano, showing quite some variety here. This reflects that even in the scientific communication the nanoterm is far from standardized. It may illustrate the fact that the missing use of the nanoterm to a large part is based on tradition, or rather the still lacking codification, institutionalization and acceptance of the nanoterminology. The incentives to communicate on nano in the scientific literature should be relatively big, considering the considerable amount of dedicated nano funding around. On the other hand, the scientific communication cannot be seen as totally separate from the public communication, as companies may consider their scientific publications as part of a wider corporate communication strategy or integrated business model.

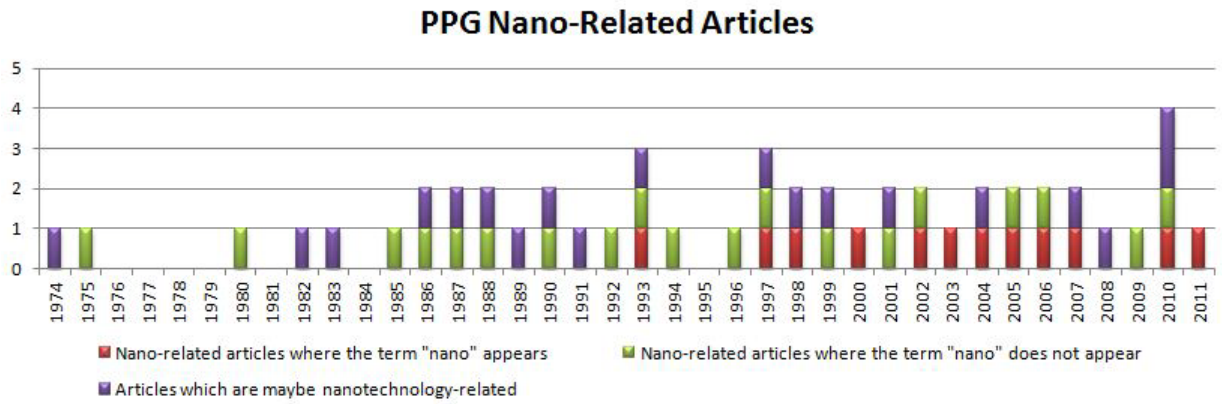
The low explicit nano scientific communication also illustrates that bibliometric analyses merely based on the nanoterm are misguiding to a high degree.

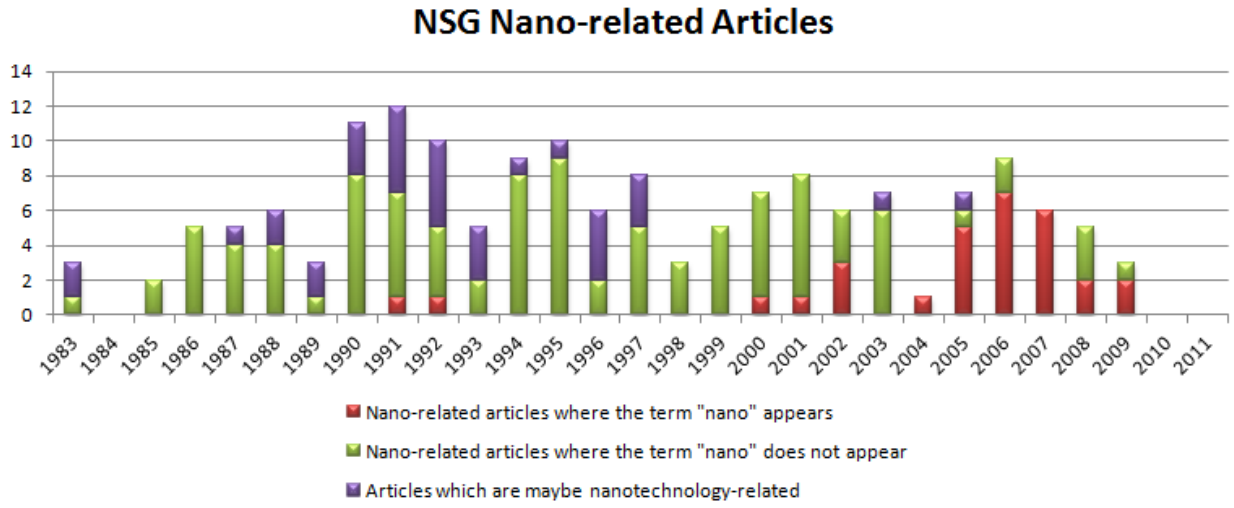
[11] The NSG articles have been analyzed somewhat quicker/less thorough than the other companies. Sisecam was not included as only four articles were identified in 2004.

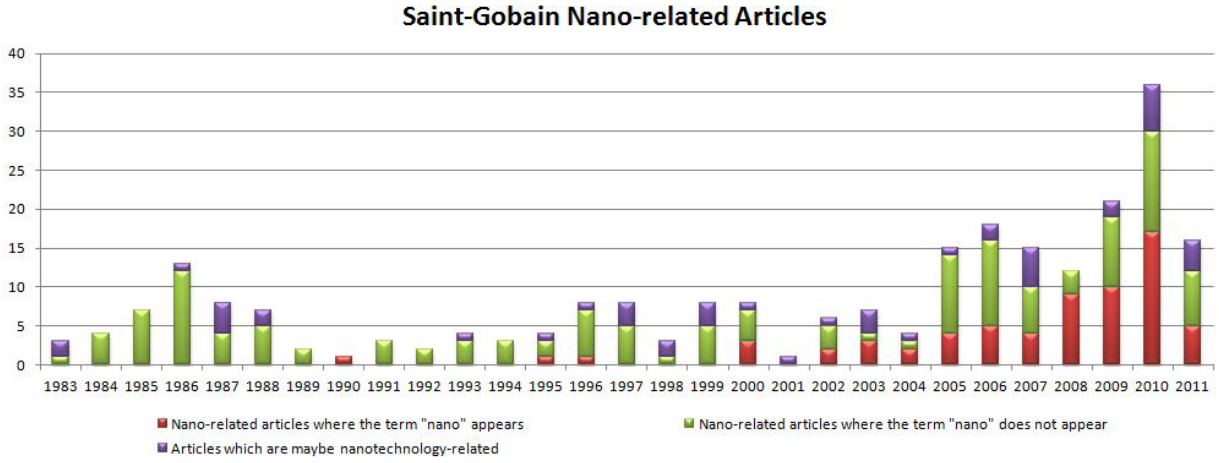
4. Analysis of nano innovation and nano transparency over time

This section seeks to track development of the nano scientific publication over time. The number of articles was plotted on histograms through the years.









Source: Own source. Notice the scales for Saint Gobain differ from those of the three other companies, because of the much higher level of nano scientific publications of this firm. Also NSG and Saint Gobains' nano R&D start later .

The main tendencies that show up are:

The first nano R&D appear in the early 1970s with a few activities only, e.g. of making memory materials of glass and ceramics, confirming the statements saying that nano R&D has been around for over 30 years in the flat glass industry. Two of the companies NSG and Saint Gobains start their nano R&D ten years later, so the development has been somewhat uneven in the beginning, both on the level of activity and the actors involved. There is quite some level of activity from the mid 1980s in all four companies, to intensify in the 2000s. The term "nano" first appears in 1990 being applied only a few times in the early

1990s by the four companies. The term begins to become established in the end 1990s being used more frequently from the 2000s. After 2005 there seems to be a marked rise in the use of the term, but again the level of activity differ somewhat between the firms and there is even a tendency for some firms for a lower explicit nano pulibcation in the last years. It is interesting to notice, that the amount of identified nanoactivities that are not termed ‘nano’ in the scientific articles remain quite high up through the 2000s.

4. Analysis of the public communication of the companies and their transparency

In this section the public communication of the firms are given, adding findings from NSG, AGC and Sisecam. The methodology of the analysis were modelled from the mentioned study by Novethic (Novethic, 2010), The goal of this analysis is to determine how companies integrate environmental and societal impacts of their activities to their communication strategy and transparency. The assessment consisted in testing various criteria in order to measure the transparency degree of the companies about their use of nanotechnologies, mainly based on website information (accessed in August 2011 and January 2012). The six main criterion were these (to each of these corresponds an amount of points) :

1. Does the term “nanotechnology” or “nanomaterial” appear on the website of the company ? (1 point)
2. In its annual reports or sustainable development report, does the company speak about nanotechnologies or nanomaterials ? (2 points)
3. Does the company give a direct contact concerning nanotechnologies ? (2 points)
4. Does the company explain what their engagements are? (3 points)
5. Does the company produce a scientific document or a deontology code about the use and/or the development of nanotechnologies and nanomaterials ? (4 points)
6. Does the company give a list of one or several of its products that contains nanotechnologies or nanomaterials ? (6 points)

Applying this taxonomy to the flat glass industry we get the following results, see table 5.

Table 5 - Notation of the transparency of the companies

Question	Pilkington	Saint-Gobain	PPG	NSG	Sisecam	AGC
#1Website	0	1	1	0	0	1
#2 Annual or sustain. Report	0	2	0	0	2	2
#3 Contact	0	0	0	0	0	0
#4 Engagement	0	3	3	0	0	0
#5 Scientific document or code	0	4	4	0	0	0
#6 List of products	0	0	0	0	0	0
Total	**0**	**10**	**8**	**0**	**2**	**3**

Source: own source.

The companies fall into three categories:

The first category gathers companies with a rather detailed communication concerning nanotechnology. Saint-Gobain and PPG are in this category. Saint Gobain, however, only obtain the classification 'basic communication' in the Novethic study, Saint Gobain being the only flat glass company in this study. These companies have a chart of development and use of nanomaterials and clearly state their position on their website. They are conscious of the issues and problems linked to nanotechnologies and they seek to contribute to the solutions by having a public communication on their nanoactivities. However, an issue not dealt with by Novethic is how nano may form part of the firms' business model,i.e. to what degree nano is seen as a possible means of creating value to the firm, rather than merely measuring the degree and seriousness of the nano (risk) communication. There is an important difference in whether firms have a defensive versus a more proactive strategy towards nanotechnology. E.g. PPG seems here to be the company which most positively seeks to brand itself as a nano company, which really is an

exception among the big players .Saint Gobain may have an extensive communcation but it is more cautious and defensive, rather than an active nano marketing directed at the market. For example Saint Gobain did not wish to participate in a special glass session organized at a nano conference in 2008, as they did not wish to be associated publicly with nano activities, despite the scientific nature of this conference. [12]

The second category contains AGC and Sisecam that evokes nanotechnology but only briefly and must be seen in the lower end of the Novethic 'basic communication' category. The last category is the silent companies, here Pilkington and NSG, not so surpricing that they are in the same category since they are within the same Group. The companies do not refer to nanotechnology on their website or in their company material at all.

The distribution of communication level seems overall fairly well in accordance with the findings of the Novethic public communication study, showing quite a high disparity in the level and type of communication . The analysis becomes the more interesting when compared to the scientific publications/communications. Unfortunately, the public communication is only a current snap shot study while we lack the development in public communication over time. None the less, it is interesting to notice, that while Pilkington and NSG are silent in their public communication, they are becoming more explicit in their scientific publications. It seems Saint Gobain is the most active in nano R&D which may explain their relatively high level of nano public communication. A high level of nano R&D does not necessarily correlate with a high level of public communication as illustrated by the case of AGC, though the activities of this company is in need of further study.

Overall, we can clearly demonstrate that all the firms do undertake nano R&D which to quite a high degree is not communicated very clearly. For further explanations into the drivers and barriers of nano

[12] The session was organized by the author and was part of the NanoTech Northern Europe Conference 2008 in September in Copenhagen.

business model formations we need more in depth qualitative studies, also to understand changes in innovation conditions over time.

Conclusions

This paper has sought to shed light on the co-evolution of technologies and markets in the case of nanotechnology. The focus on the neglected market formation aspects of emerging technologies has highlighted the high transaction costs and high uncertainties to new technologies because of lacking market supporting institutions which has led to a widespread silent nature of the nano market. The hype features specific to nanotechnology, but resembling that of biotechnology, is a significant factor here giving rise to high and early attention to risk issues in firms' strategies; but the explanation seems also to lie among the general uncertainty and costs related to communicating nanotechnology as well as a reluctance to take on the new nanoterm for existing practices. The silent nano market is hence more than a risk discussion.

Firms seem to be developing nano business models where risk management forms an integrated part and where communication strategies are carefully developed none the less, either consciously being outspoken, or consciously being silent. Both strategies seem to play a fairly equal role at the moment. At the moment the dominating nano business model seems to be more defensive than proactive, reflecting the fact that currently it is little attractive for firms to brand themselves as a nano company. The transaction costs and uncertainties are too high and the profit opportunities to low. The extent of the silent nature of firm nano communication as illustrated by the flat glasss industry ,has shown to be very widespread, albeit of an uneven nature. As a consequence nano hardly functions as a selection criteria on the market currently, which is likely to slow down the commercialization process; it may even indicate that nanotechnology will never materialize into a distinct technology but much can still happen in nanotechnology evolution whose gestation period may be very long yet.

An important argument of this paper has been to point to the significance of situating firm communication activities within a wider business model, rather than merely looking at the extent and

accuracy of the public nano communication as is the focus of much risk analysis. Only when seen in a business model context it is possible to look into the drivers and barriers for firms' nano strategies, whether these are directed at undertaking nano R&D or directed at market and stakeholder communication.

The paper has further argued for the need for in-depth sector specific analysis in order to uncover the extent and nature of the nanoactivities and the nano communication. Comparing public communication with scientific communication (publications) seems a promising endavour for uncovering the co-evolution of technologies and markets, over time albeit more detailed longitudional studies, including, patent and qualitative studies, are needed. The primarily bibliometric methodology used here is in need of further empirical analysis into larger populations of firms, including other actors in the value chains, and none the least the possible important role of up-start companies, not only for developing nanotechnologies but also as proactive makers of markets for nanotechnology. Also, the findings should be compared to studies into other emerging technologies such as biotechnology.

Overall, analyzing the case of nanotechnology evolution seems to illustrate the rising importance of social and legitimacy aspects as well as the formation of institutions of emerging technologies in modern knowledge economies. At the current early stage the nano market is immature and market-supporting institutions (e.g. standards, documentation, language, regulations) are not in place. Therefore, the firms which will profit from their engagements in nanotechnology innovation at the current early stage have to build up nanotechnology business model which either invests in building the lacking market supporting institutions or maneuvers without these, carefully dealing with risk issues and how to market nano activities and address social needs.

The policy implications of this analysis are significant pointing to the insufficiency in merely investing in R&D (which by far is the main nanotechnology policy instrument so far) in an emerging technology while neglecting investing in building market supporting institutions timely to facilitate and efficient commercialization process.

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